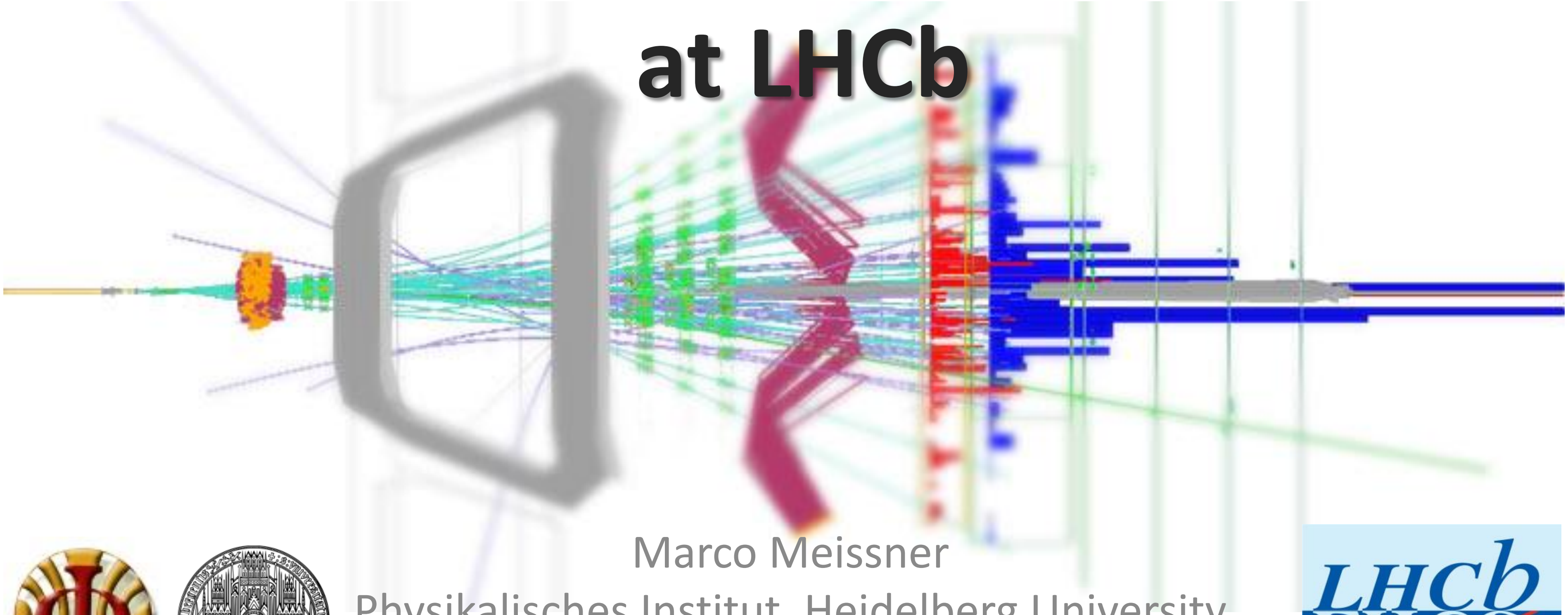
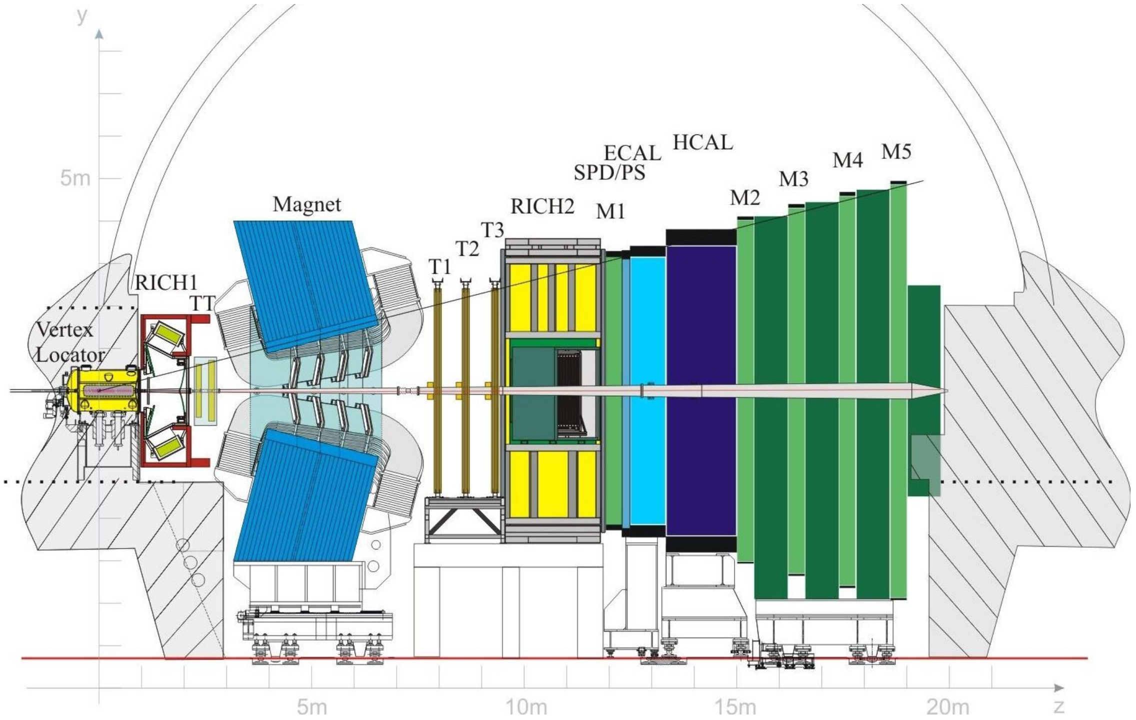
HEP 2013
Stockholm
18-24 July 2013
(info@eps-hep2013.eu)

Studies of Soft-QCD at LHCb



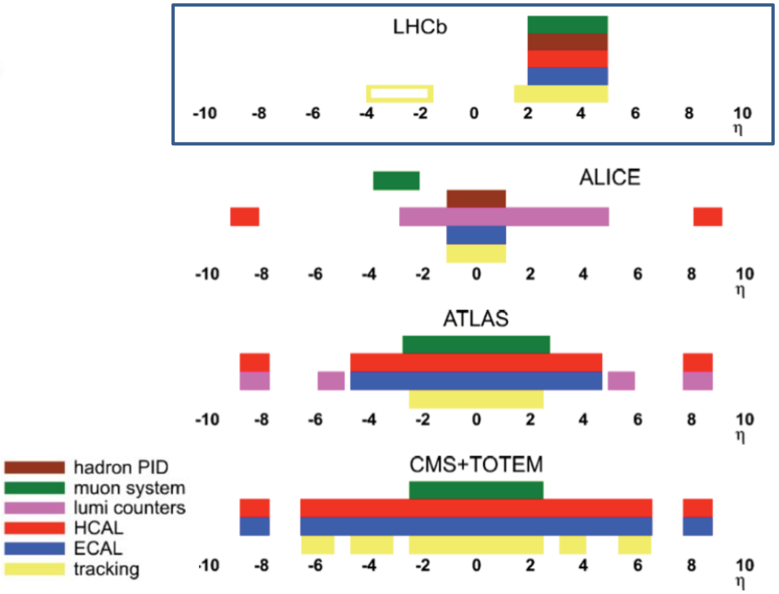
Marco Meissner
Physikalisches Institut, Heidelberg University
on behalf of the LHC*b* collaboration

Introduction



LHCb has great potential for
Soft-QCD measurements

- Excellent vertex resolution & coverage of backwards tracks
- Particle ID from Ring Imaging Cherenkov detectors
- Unique pseudorapidity coverage at the LHC ($2 < \eta < 5$)



Recent QCD studies which are presented in this talk:

- Energy Flow measurement
- Prompt Hadron Ratios
- Prompt Charm production

Energy Flow

Eur. Phys. J. C (2013) 2421

Energy Flow (EF): $$\frac{1}{N_{int}}\frac{dE_{total}}{d\eta} = \frac{1}{\Delta\eta}\left(\frac{1}{N_{int}}\sum_{i=1}^{N_{part,\eta}} E_{i,\eta}\right)$$

energy per particle

inelastic interactions

- Energy Flow at large pseudorapidity probes multi-parton-interactions (MPI) & parton radiation
- MPI describes the structure of the underlying event
- Valuable input for generator tunings
  Comparison to *PYTHIA* and *cosmic-ray* event generators

Energy Flow measured in 4 different event classes:

- Inclusive minimum-bias: at least 1 track in $1.9 < \eta < 4.9$ and $p > 2$ GeV
- Hard- scattering: at least 1 track in $1.9 < \eta < 4.9$ and $p_T > 3$ GeV
- Diffractive enriched: no tracks in $-3.5 < \eta < -1.5$
- Non-diffractive enriched: at least 1 track in $-3.5 < \eta < -1.5$

Large rapidity gap for diffractive processes

Energy Flow

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Total EF = (charged + neutral) EF

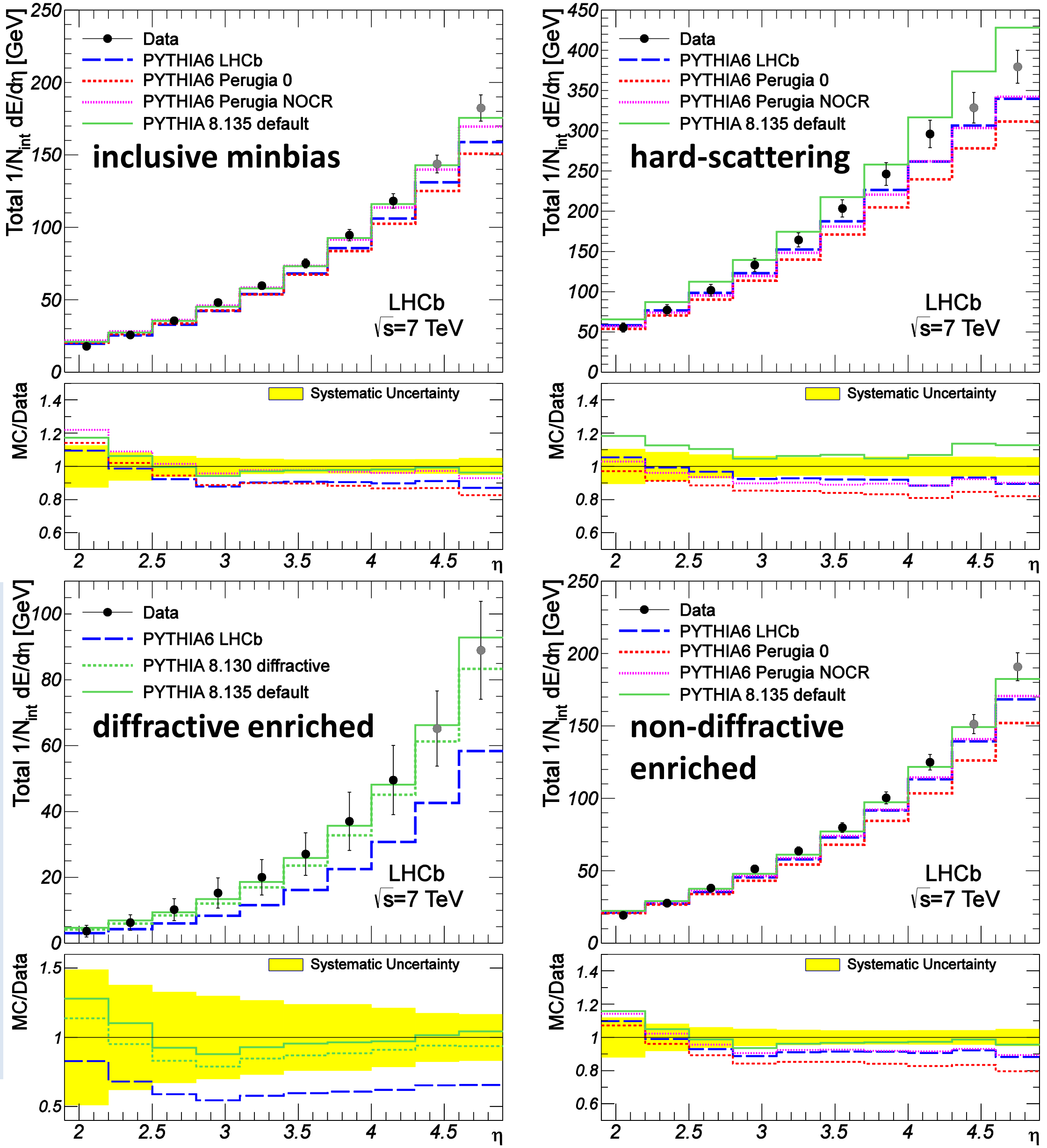
- Energy Flow increases with larger momentum transfer: $EF_{hard} > EF_{non-diff} > EF_{incl} > EF_{diff}$

- Uncertainties dominated by systematics
- Uncertainties decrease towards larger η

Compared to **PYTHIA** predictions

- PYTHIA 6 tunes:
  for all samples the EF is
  -> overestimated at small η
  -> underestimated at large η

- PYTHIA 8 tunes:
  EF in all samples is well described at large η, except for hard scattering



Energy Flow

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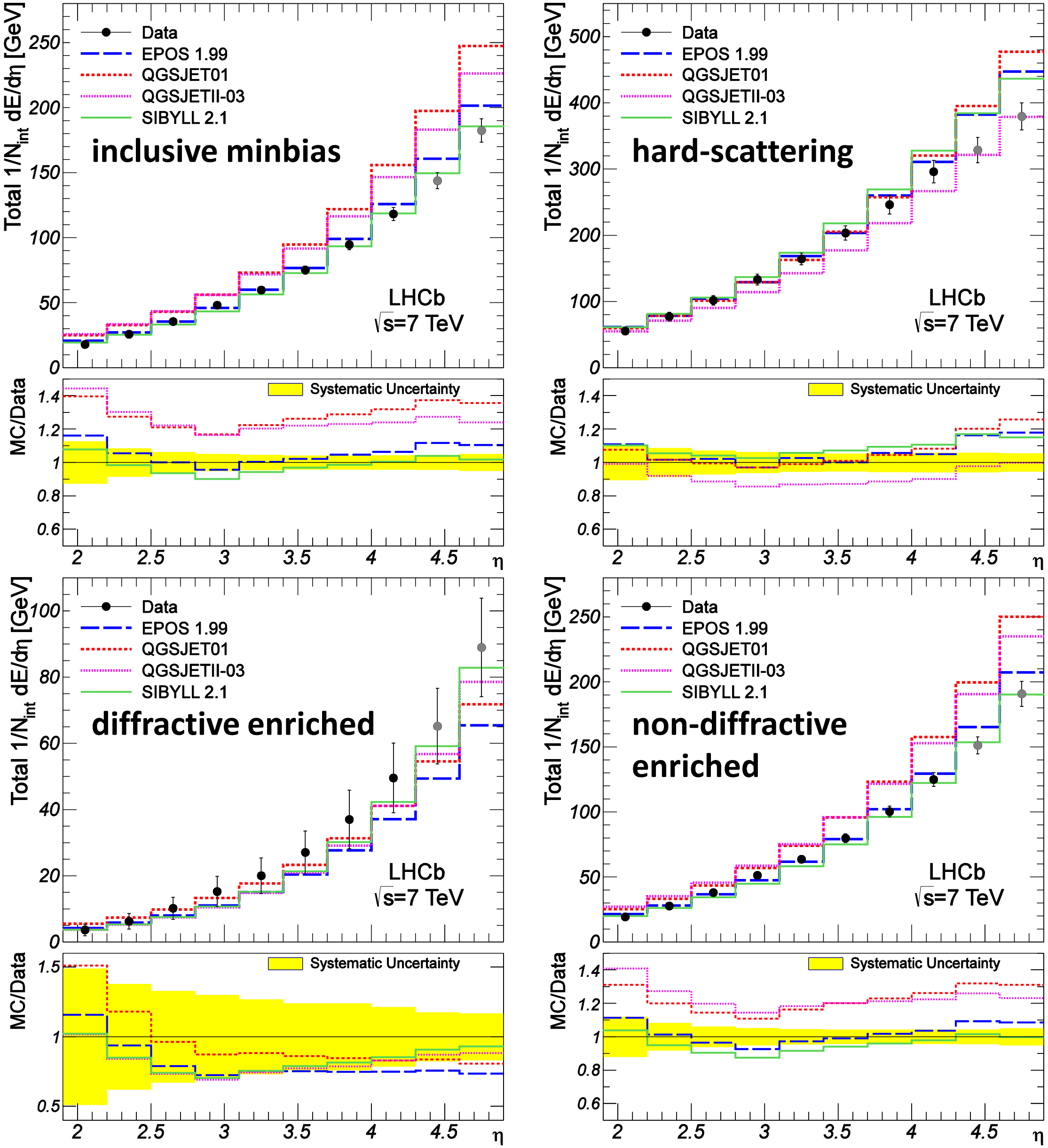
Compared to **cosmic-ray** generators
(not tuned to LHC data!)

- EPOS & SYBILL
  good description of minimum-bias and non-diffractive events
- QGSJET models
  overestimated EF in minimum-bias and non-diffractive events, but good description of hard scattering
- Best description by SYBILL
- All models underestimate EF in the diffractive sample

input for PYTHIA & cosmic-ray generators!



Prompt Hadron Ratios

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Analyzed data: $0.3nb^{-1}$at $\sqrt{s}$ = 0.9TeV and $1.8nb^{-1}$ at $\sqrt{s}$ = 7TeV

Measured ratios as function of η and p_T:

Same-particles $\frac{K^-}{K^+}, \frac{\pi^-}{\pi^+}, \frac{\bar{p}}{p}$ Different-particles $\frac{p+\bar{p}}{\pi^+ + \pi^-}, \frac{K^+ + K^-}{\pi^+ + \pi^-}, \frac{p+\bar{p}}{K^+ + K^-}$

- $\overline{p}/p$ is an observable to test *baryon number transport*

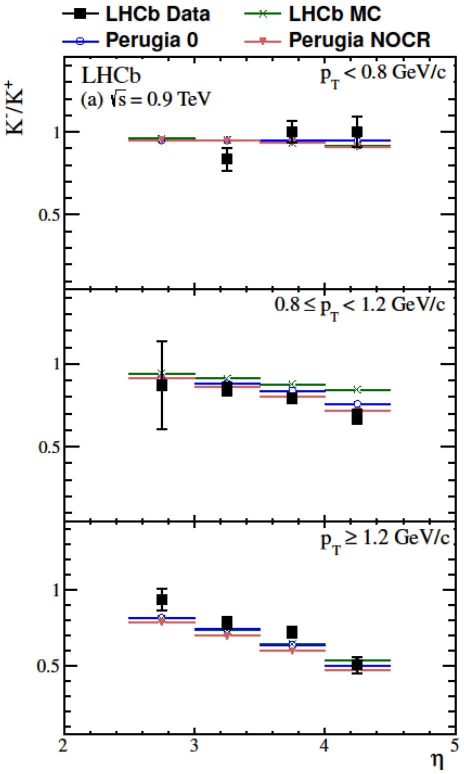
- All ratios are probes for hadronisation models
  -> import input of generator optimization

- PID efficiencies from data using resonances: $K_S^0 \rightarrow \pi\pi$, $\phi \rightarrow KK$ and $\Lambda \rightarrow$ pπ
- Dominant systematic uncertainty from PID due to limited calibration sample size

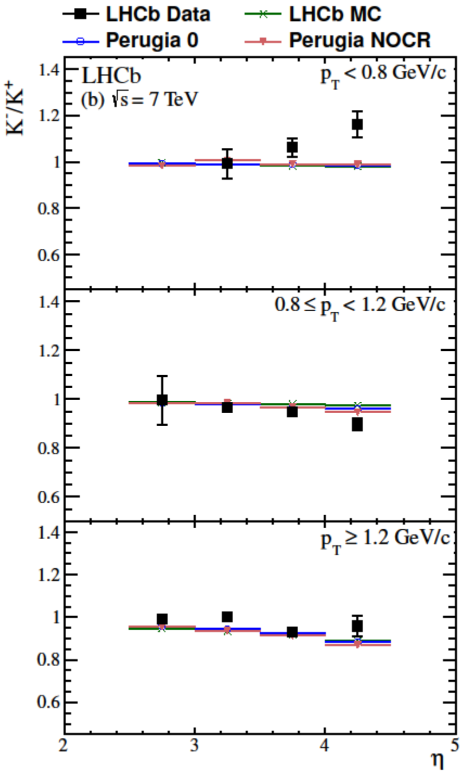
Same-particle ratios

K^-/K^+

$\sqrt{s}$ =0.9 TeV

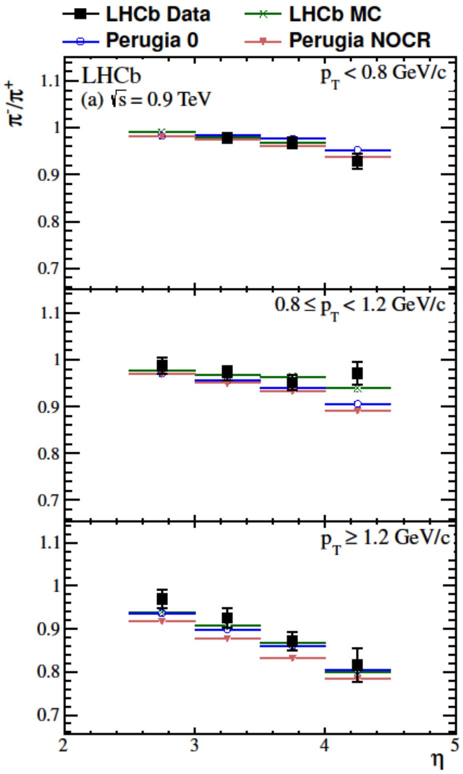


$\sqrt{s}$ =7 TeV

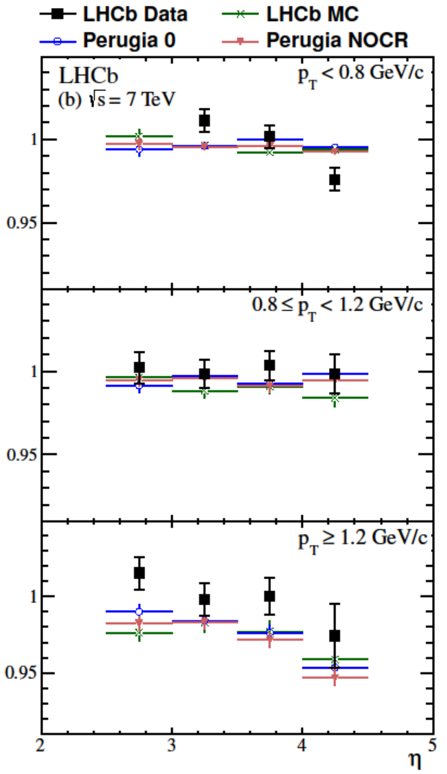


π^-/π^+

$\sqrt{s}$ =0.9 TeV



$\sqrt{s}$ =7 TeV



- Ratios close to unity
- In general K^-/K^+ and π^-/π^+ well described by tested PYTHIA generator tunes

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Same-particle ratios

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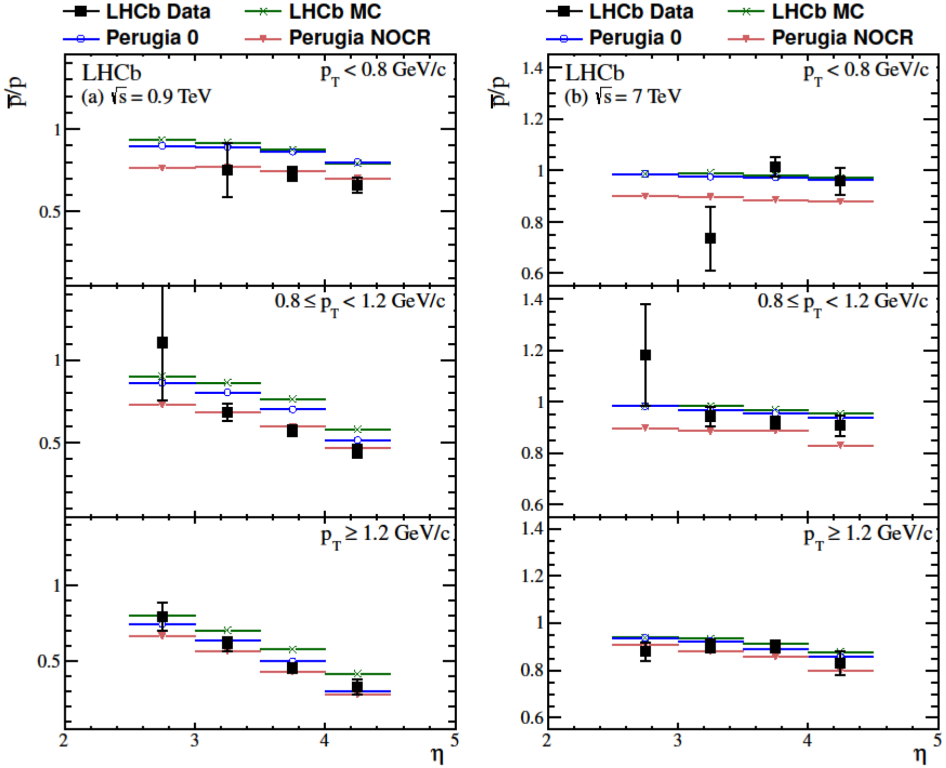
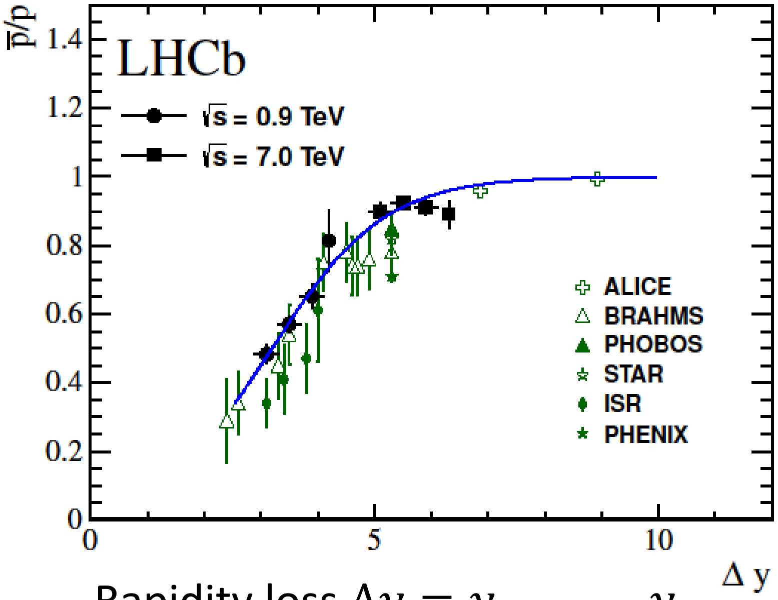
$\sqrt{s}$ =0.9 TeV

$\sqrt{s}$ =7 TeV

$\bar{\text{p}}/\text{p}$





Rapidity loss $\Delta y = y_{beam} - y$

y_{beam}= 8.9 (6.9) at $\sqrt{s}$ = 7 (0.9) TeV

- For 0.9 TeV $\bar{p}/p$ shows significant η dependence, model with extreme baryon number transport (NOCR) favored
- For 7 TeV Perugia0 and LHCb tune better than NOCR tune

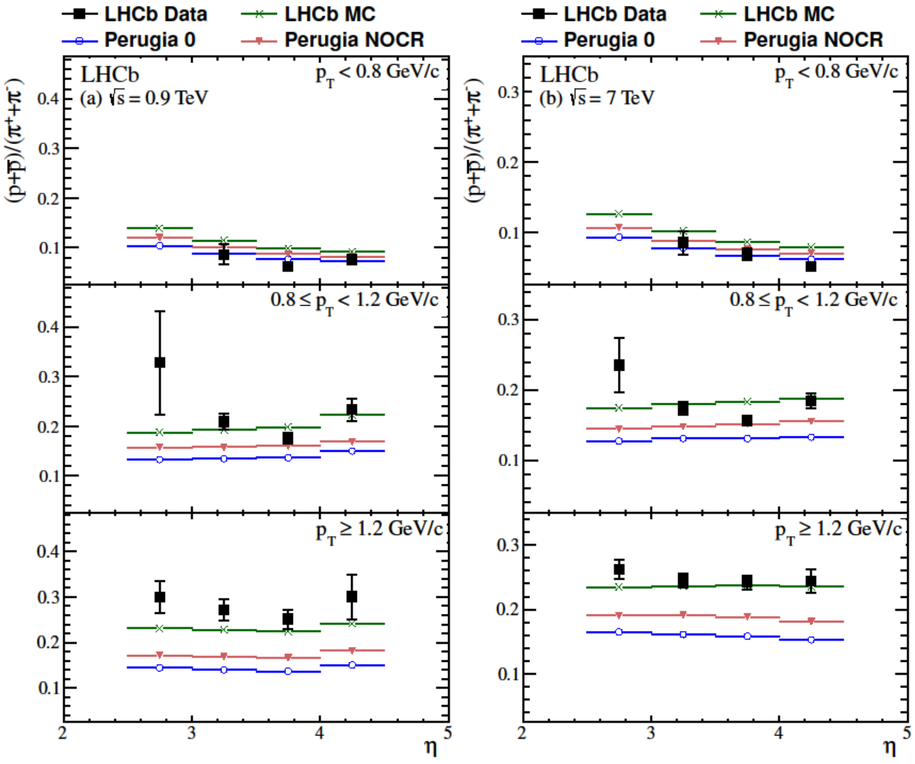
- $\bar{p}/p$ as function of rapidity loss: consistent results, much better precision
- Fit to LHCb & ALICE data: *Regge model* of baryon transport

Different-particle ratios

$$\frac{p+\overline{p}}{\pi^+ + \pi^-}$$

$\sqrt{s}$ =0.9 TeV

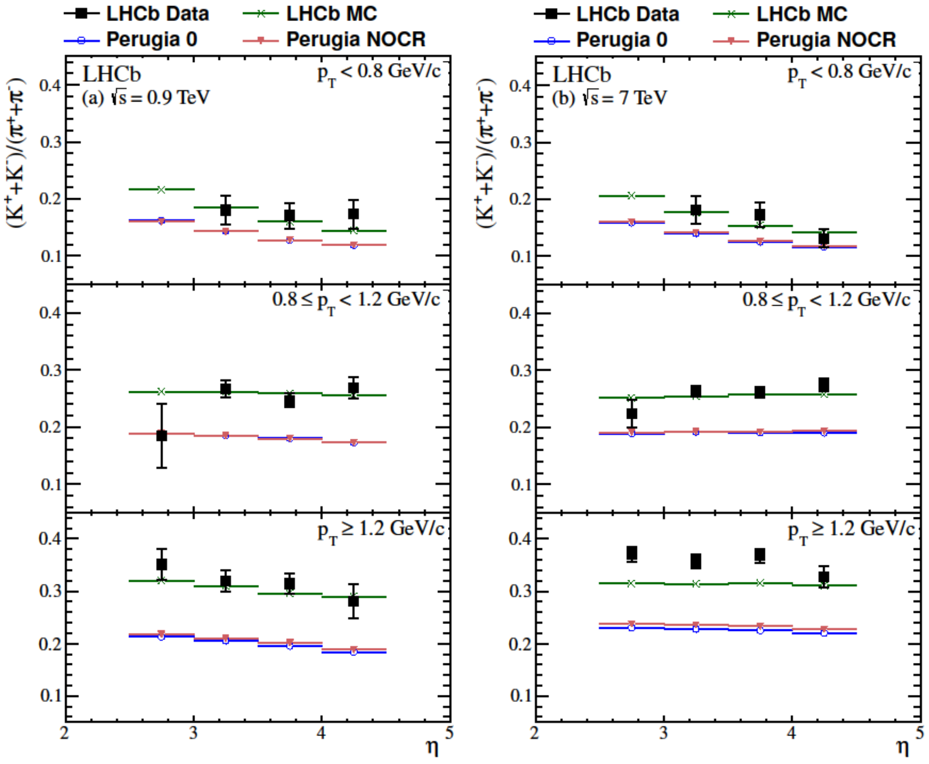
$\sqrt{s}$ =7 TeV



$$\frac{K^+ + K^-}{\pi^+ + \pi^-}$$

$\sqrt{s}$ =0.9 TeV

$\sqrt{s}$ =7 TeV



- Large discrepancies to Perugia0 and Perugia NOCR tunes
- LHCb tune is fine

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- In general, no model is able to describe the whole measurements

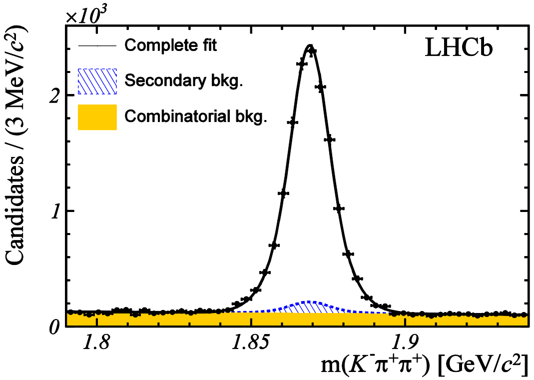
Prompt Charm Production

Nucl. Phys. B 871 (2013)

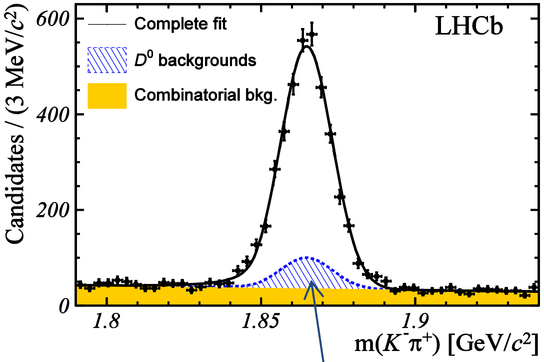
➢ Cross-section measurement tests QCD **fragmentation** and **hadronisation** models

- $\sqrt{s}$ = 7TeV data set, $\mathcal{L}$=0.15nb^{-1}
- Fiducial region:
  2.0 < η < 4.5; 0 < p_T < 8 GeV
- Use fully reconstructed decays of prompt charm hadrons: $\boldsymbol{D^0}$, $\boldsymbol{D^+}$, $\boldsymbol{D^{*+}}$, $\boldsymbol{D_s^+}$ and $\boldsymbol{\Lambda_c^+}$
- PID efficiencies from data using K_S^0, ϕ and Λ decays
- Prompt signal yield gained from multidimensional extended maximum likelihood fit (mass + IP distribution)

$\boldsymbol{D^+ \rightarrow K^-\pi^+\pi^+}$

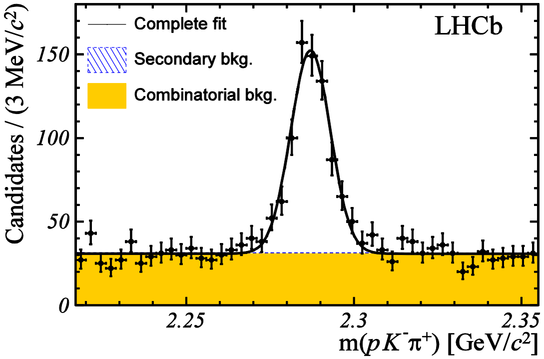


$\boldsymbol{D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+}$



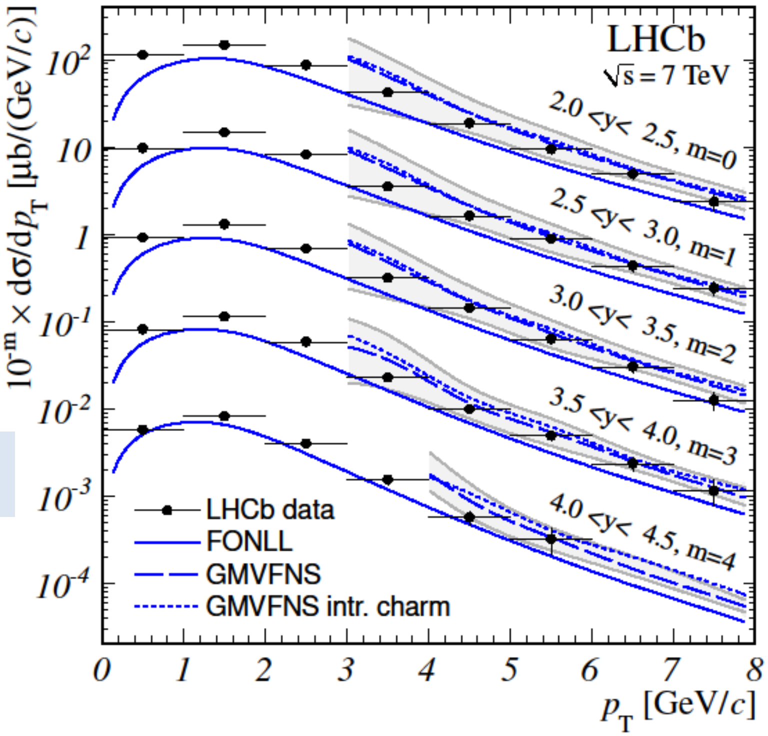
additional BG from prompt and secondary slow pions

$\boldsymbol{\Lambda_c^+ \rightarrow p\,K^-\pi^+}$

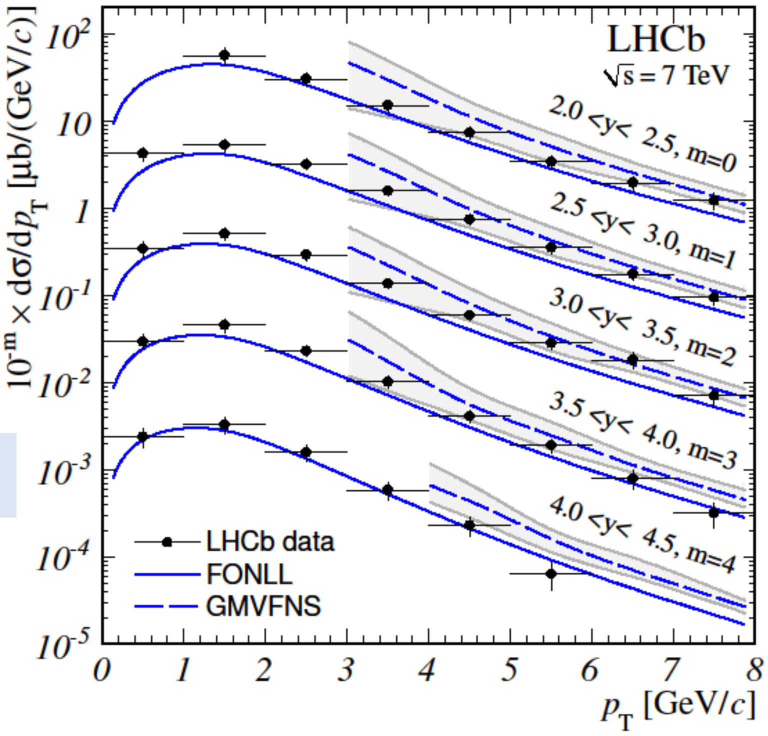


Prompt Charm Production

D^0



D^+



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Differential cross-sections compared to theoretical expectations, which reproduce Tevatron & ALICE measurements in central rapidity region

- Fixed order with next to leading-log resummation (**FONLL**) using CTEQ 6.6
- NLO calculation in the *Generalized Mass Variable Flavour Number Scheme* (**GMVFNS**) using CTEQ 6.5 and CTEQ 6.5c2 (**intrinsic charm**)

  - ➢ Good agreement with our measurement
  - ➢ Effect of intrinsic charm is predicted to be small in this phase space region

Prompt Charm Production

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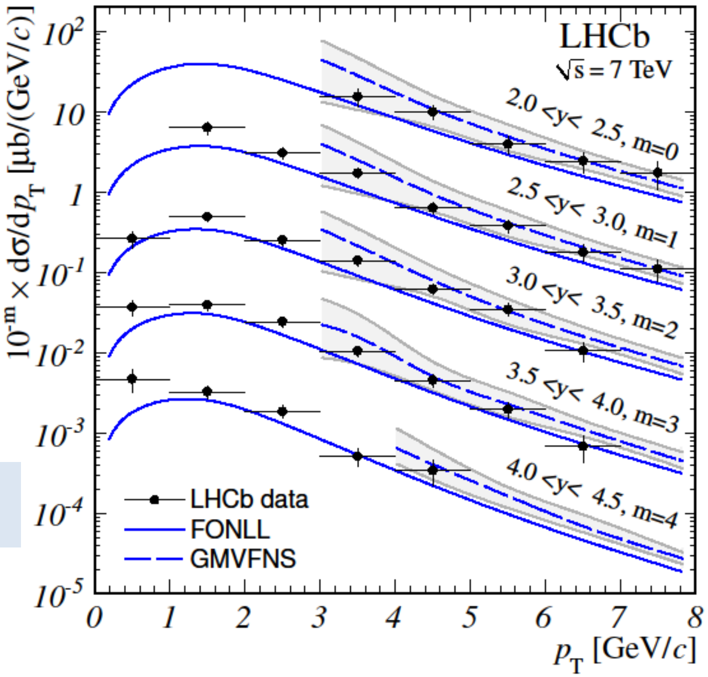
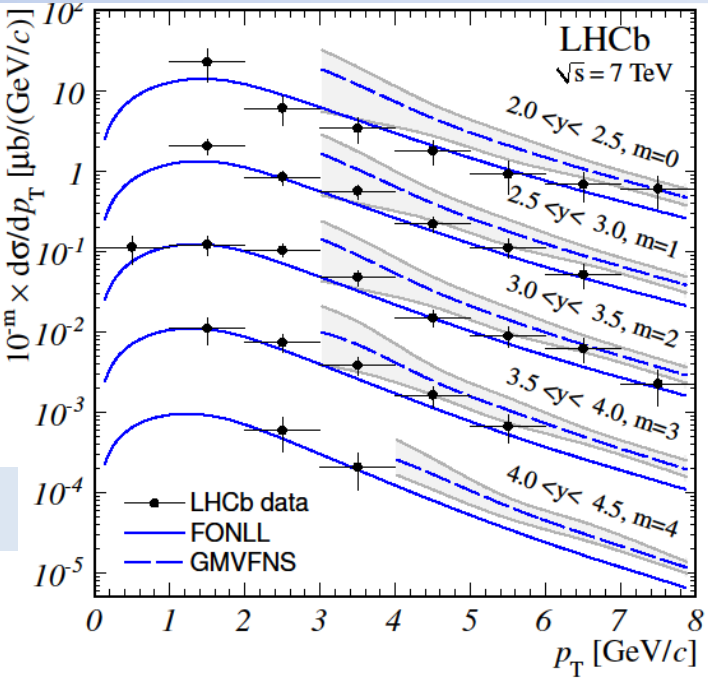
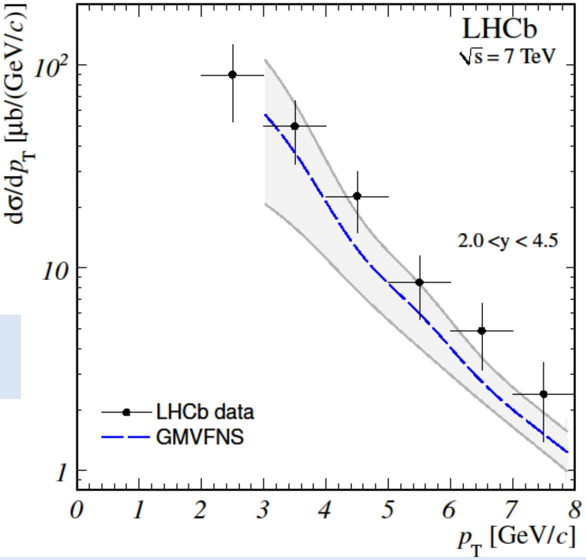
D^{*0}



D_s^+



Λ_c^+

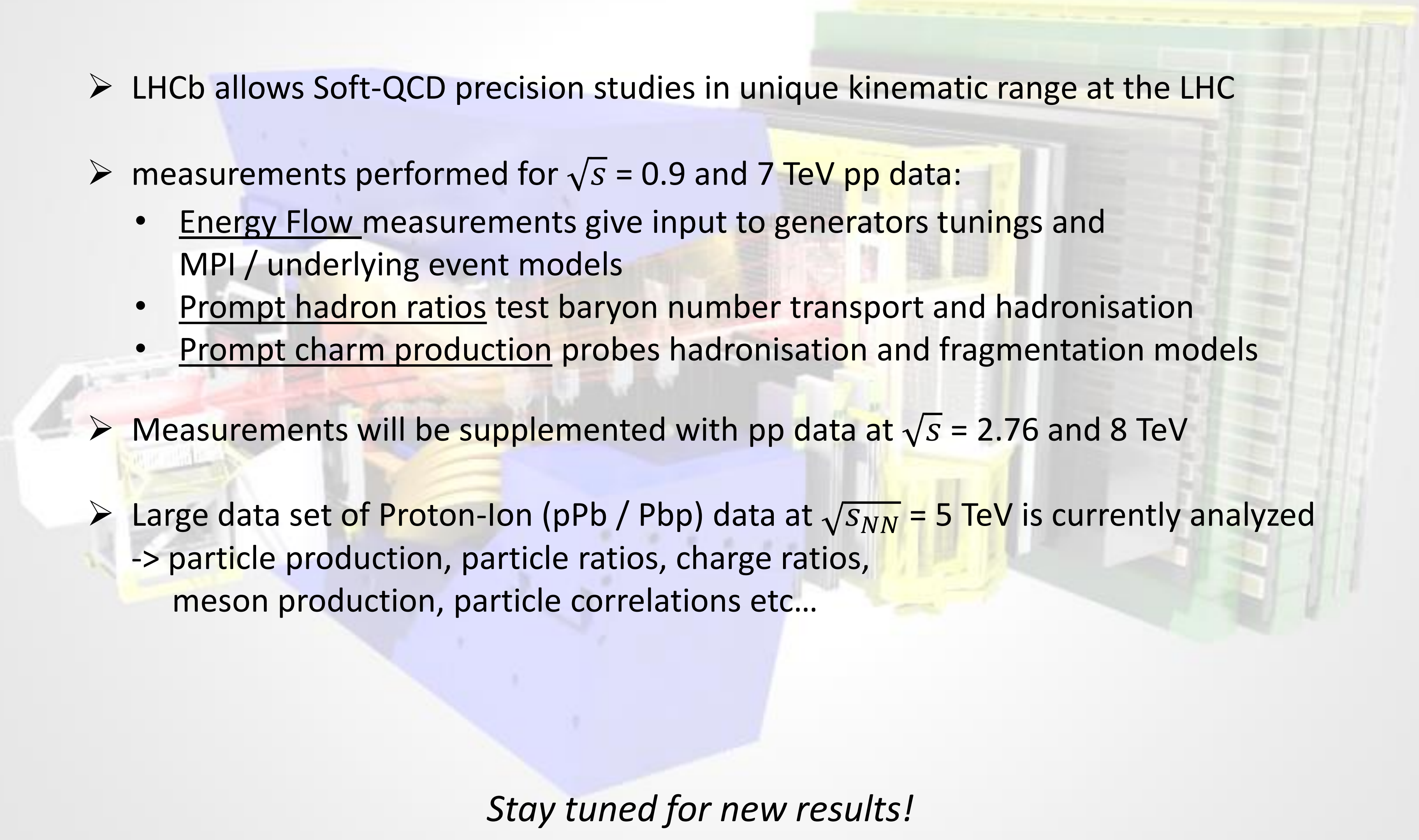


- Good agreement in these modes as well
- Total charm cross-section* (p_T<8GeV, 2.0<η<4.5):

$\sigma(c\bar{c})$ = 1419±12(stat) ± 116(syst) ± 65 (frag) μb

* Combination of bins where rel. precision < 50%, otherwise using extrapolation based on Pythia tunes (Perugia0, PerugiaNOCR, Perugia2010 & LHCb tune)

Summary



- LHCb allows Soft-QCD precision studies in unique kinematic range at the LHC

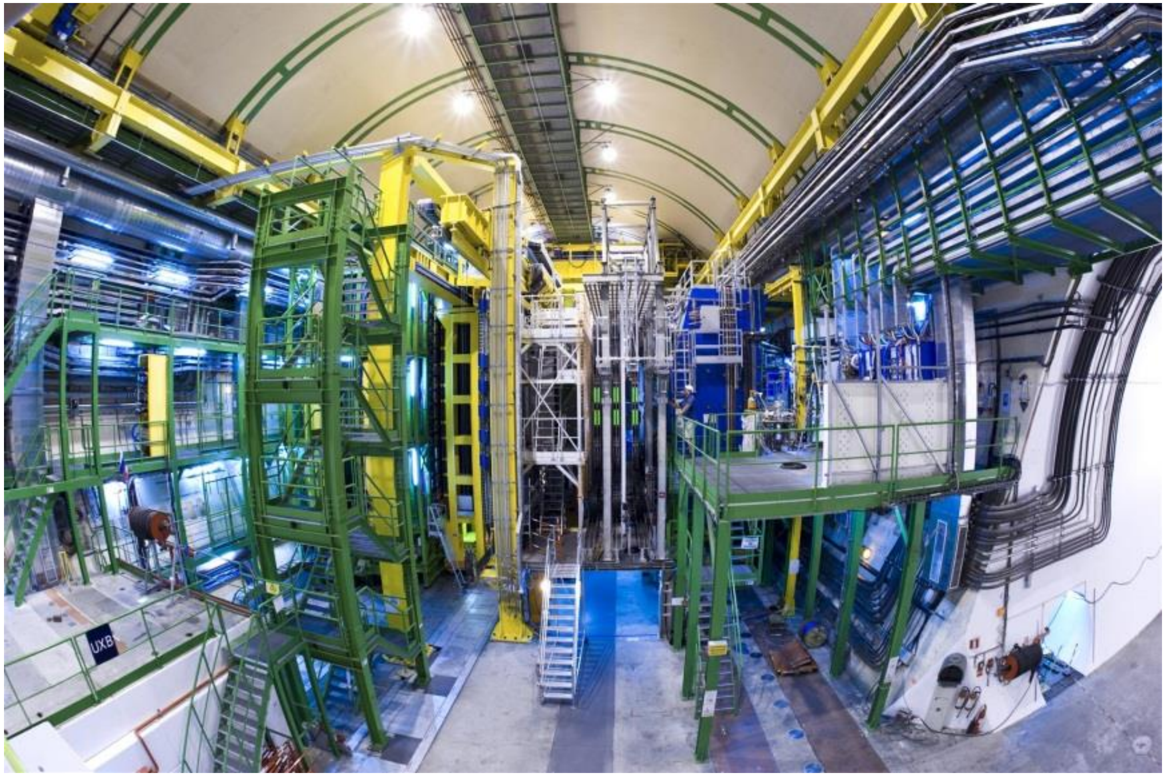
- measurements performed for $\sqrt{s}$ = 0.9 and 7 TeV pp data:
  - Energy Flow measurements give input to generators tunings and MPI / underlying event models
  - Prompt hadron ratios test baryon number transport and hadronisation
  - Prompt charm production probes hadronisation and fragmentation models

- Measurements will be supplemented with pp data at $\sqrt{s}$ = 2.76 and 8 TeV

- Large data set of Proton-Ion (pPb / Pbp) data at $\sqrt{s_{NN}}$ = 5 TeV is currently analyzed
  -> particle production, particle ratios, charge ratios,
  meson production, particle correlations etc…

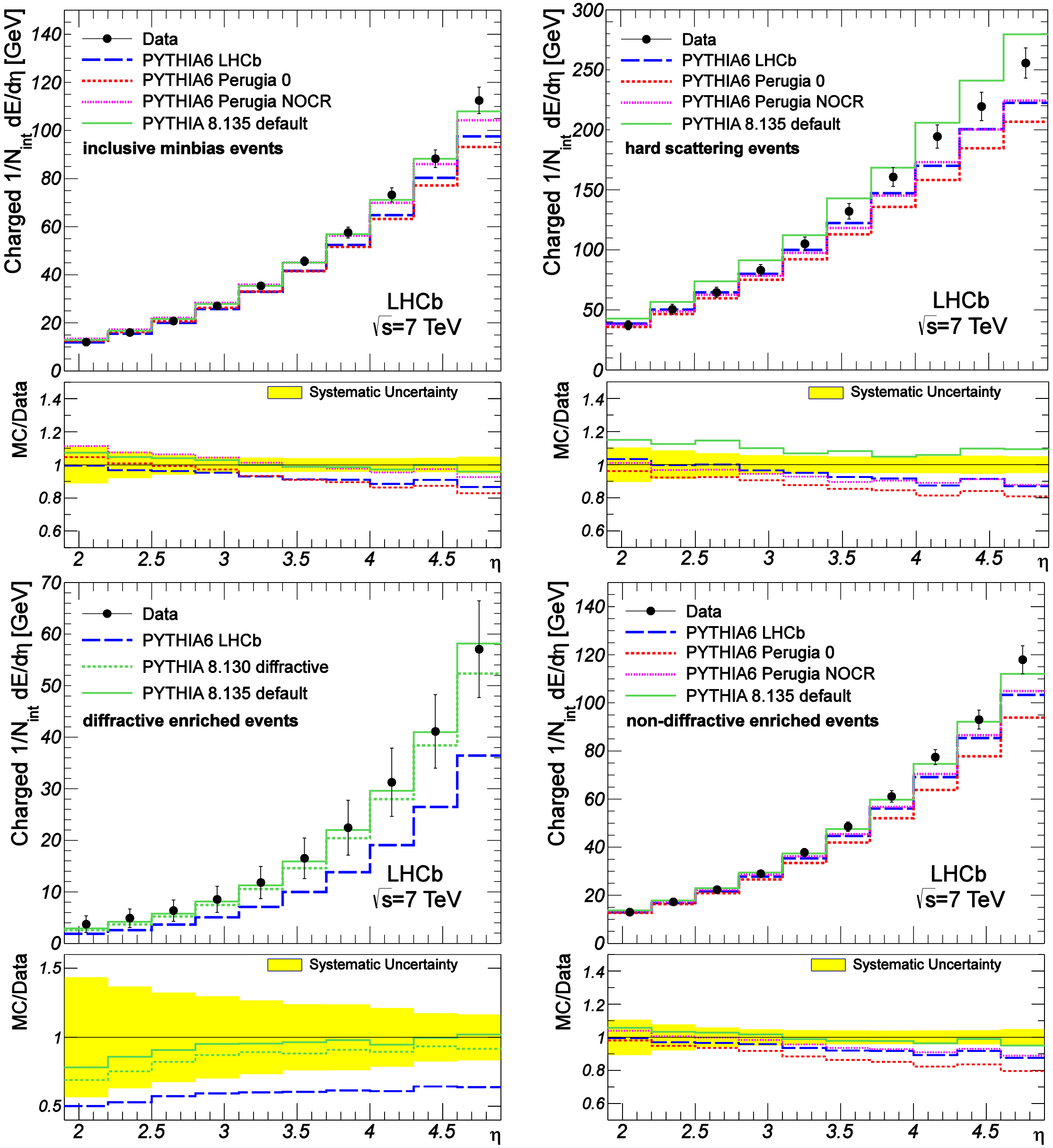
Stay tuned for new results!

BACKUP



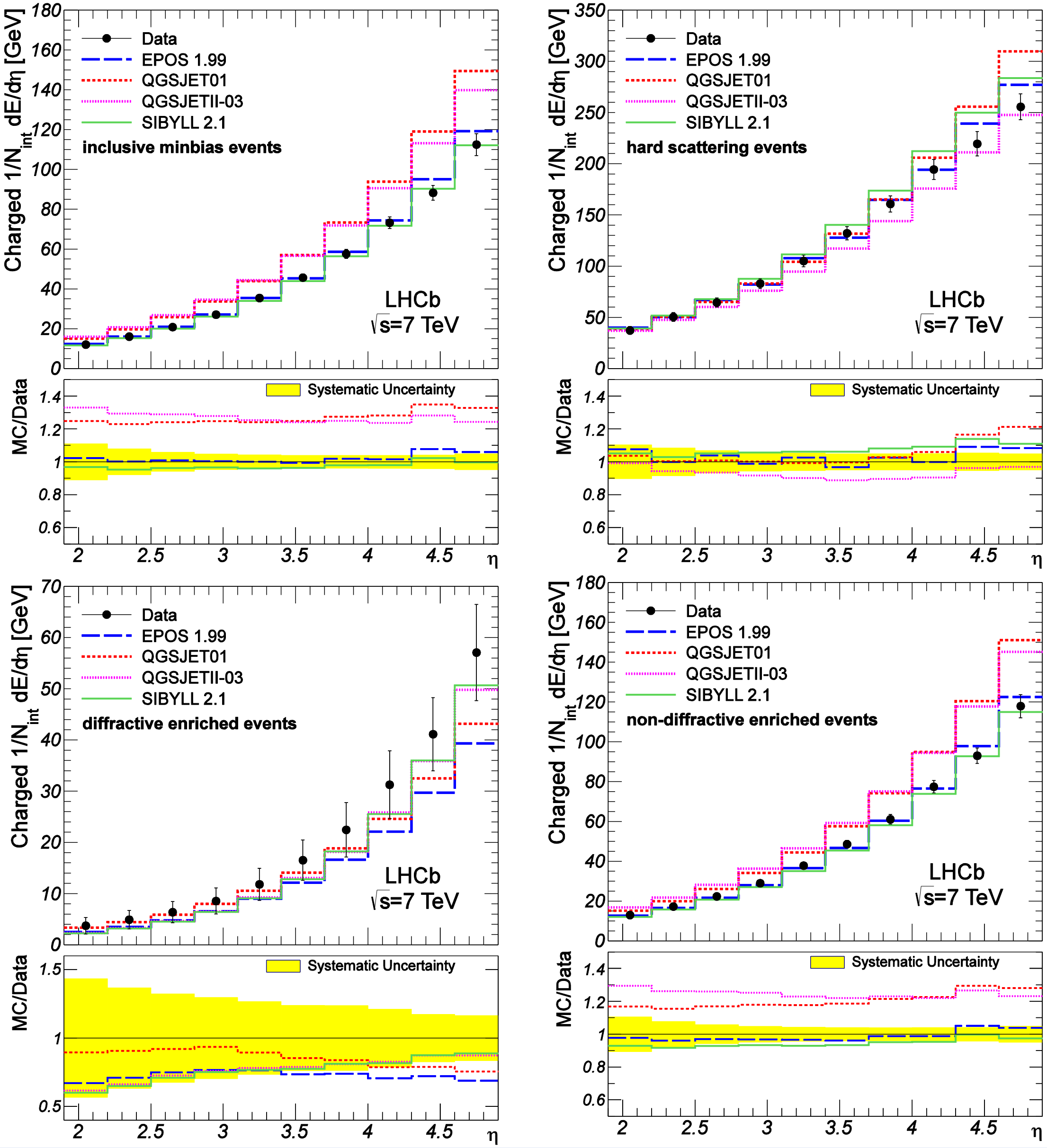
Energy Flow

Charged Energy Flow



Energy Flow

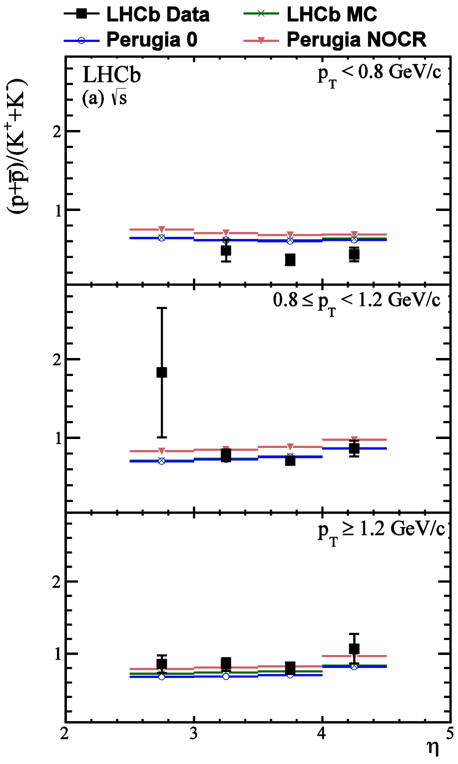
Charged Energy Flow



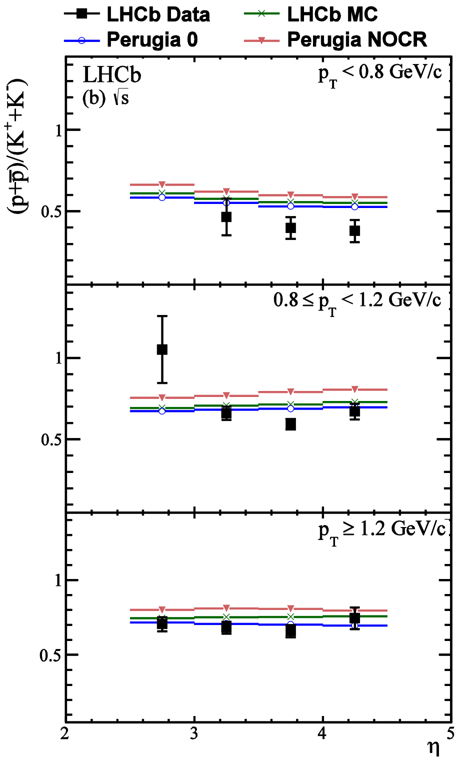
Different-particle ratios

$$(\mathbf{p}+\overline{\mathbf{p}})/(K^{+}+K^{-})$$

$\sqrt{s}$ =0.9 TeV



$\sqrt{s}$ =7 TeV



Prompt Charm Production

Prompt charm production in *pp* collisions at $\sqrt{s}$ = 7TeV

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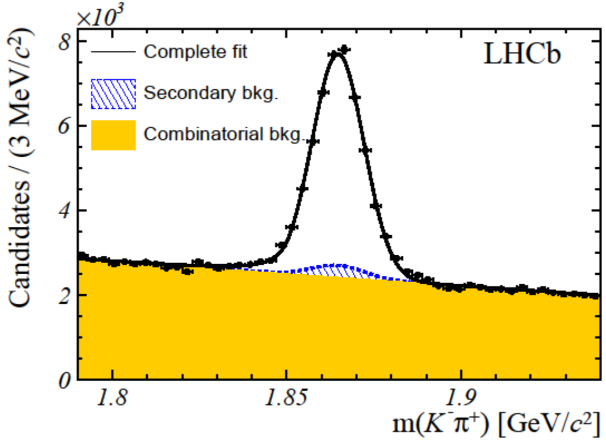
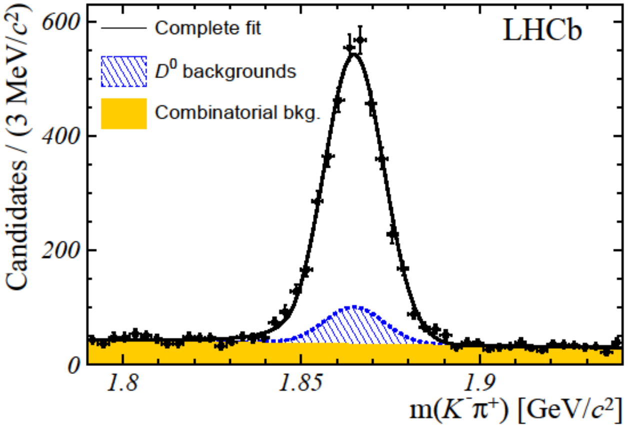
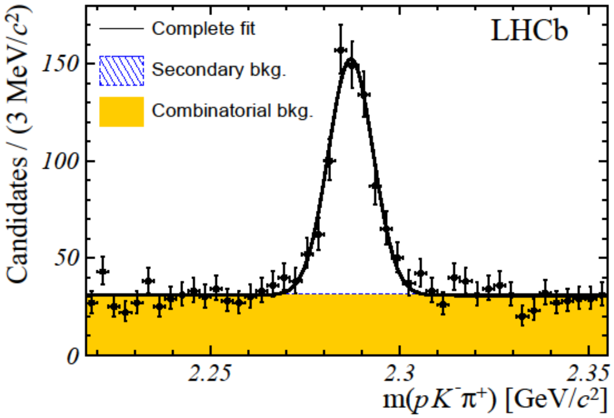
$D^0 \rightarrow K^-\pi^+$



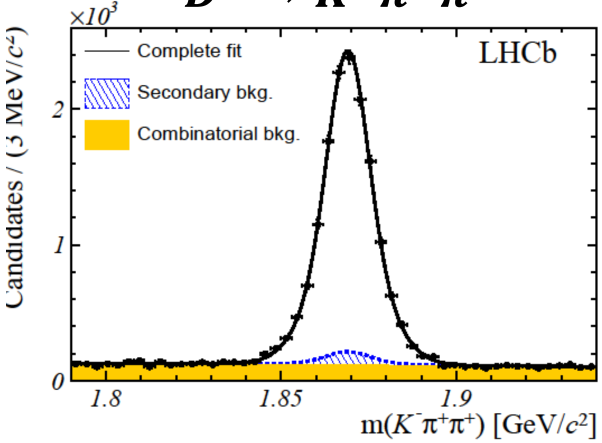
$D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$



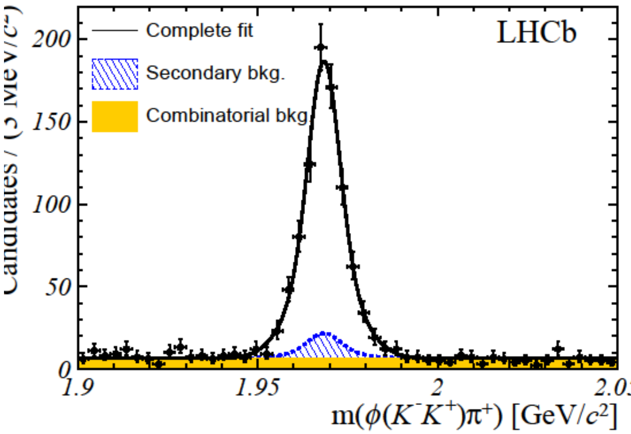
$\Lambda_c^+ \rightarrow p\,K^-\pi^+$



$D^+ \rightarrow K^-\pi^+\pi^+$



$D_s^+ \rightarrow \phi(K^-K^+)\pi^+$



Prompt Charm Production

Prompt charm production in *pp* collisions at $\sqrt{s}$ = 7TeV

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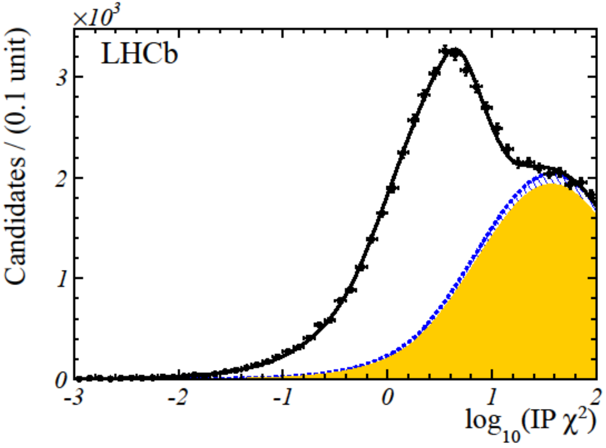
$D^0 \rightarrow K^-\pi^+$



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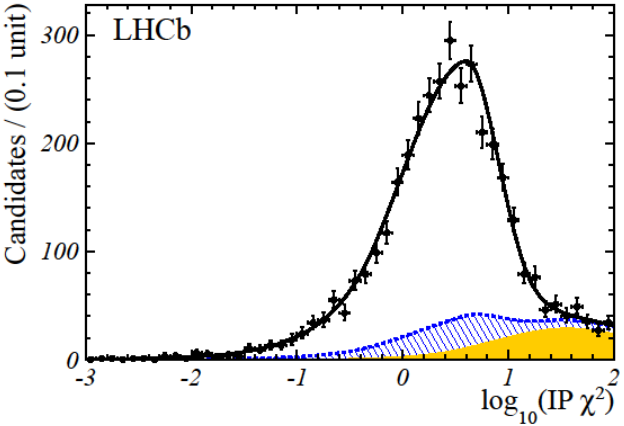
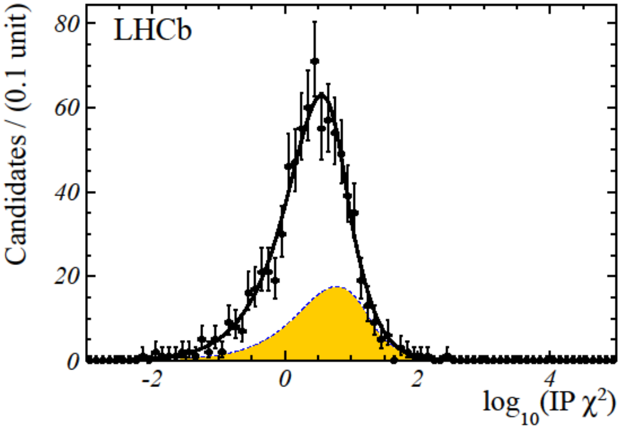
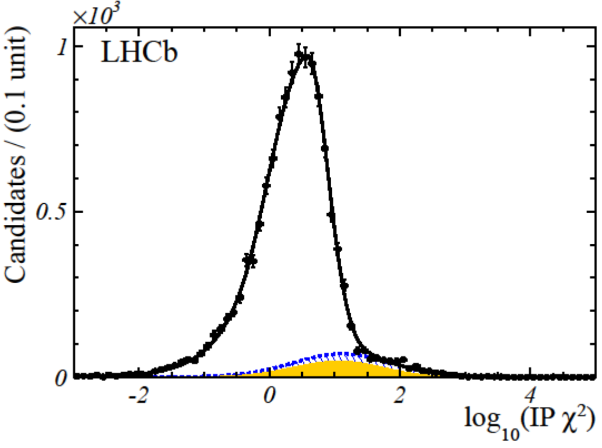


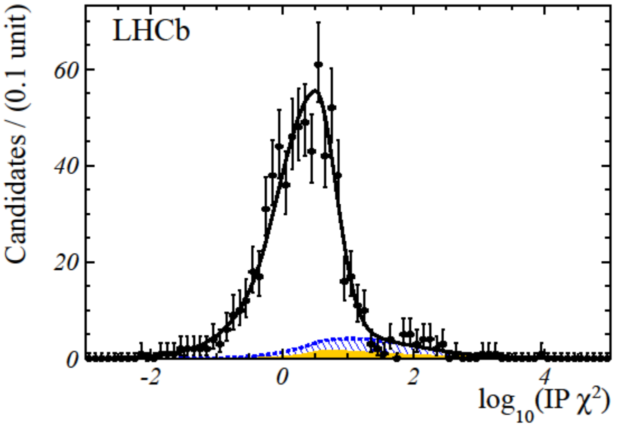
$\Lambda_c^+ \rightarrow p\,K^-\pi^+$



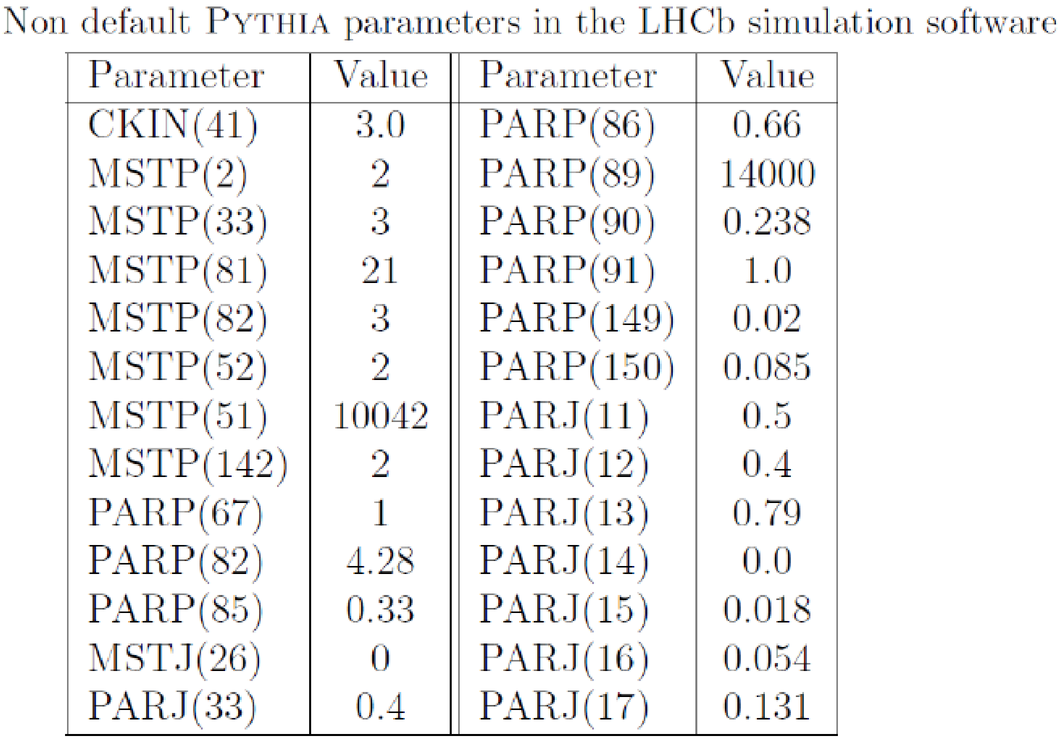
$D^+ \rightarrow K^-\pi^+\pi^+$



$D_s^+ \rightarrow \phi(K^-K^+)\pi^+$

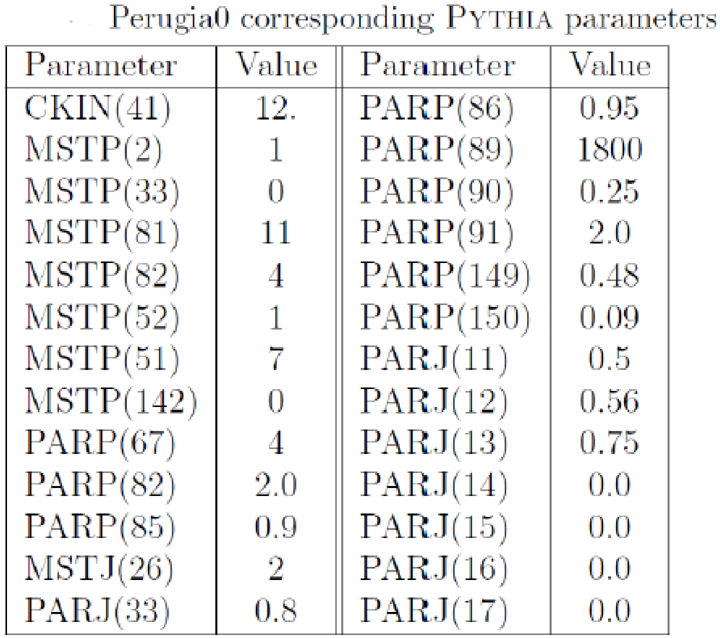


PYTHIA tunes



Non default PYTHIA parameters in the LHCb simulation software

Parameter	Value	Parameter	Value
CKIN(41)	3.0	PARP(86)	0.66
MSTP(2)	2	PARP(89)	14000
MSTP(33)	3	PARP(90)	0.238
MSTP(81)	21	PARP(91)	1.0
MSTP(82)	3	PARP(149)	0.02
MSTP(52)	2	PARP(150)	0.085
MSTP(51)	10042	PARJ(11)	0.5
MSTP(142)	2	PARJ(12)	0.4
PARP(67)	1	PARJ(13)	0.79
PARP(82)	4.28	PARJ(14)	0.0
PARP(85)	0.33	PARJ(15)	0.018
MSTJ(26)	0	PARJ(16)	0.054
PARJ(33)	0.4	PARJ(17)	0.131



Perugia0 corresponding PYTHIA parameters

Parameter	Value	Parameter	Value
CKIN(41)	12.	PARP(86)	0.95
MSTP(2)	1	PARP(89)	1800
MSTP(33)	0	PARP(90)	0.25
MSTP(81)	11	PARP(91)	2.0
MSTP(82)	4	PARP(149)	0.48
MSTP(52)	1	PARP(150)	0.09
MSTP(51)	7	PARJ(11)	0.5
MSTP(142)	0	PARJ(12)	0.56
PARP(67)	4	PARJ(13)	0.75
PARP(82)	2.0	PARJ(14)	0.0
PARP(85)	0.9	PARJ(15)	0.0
MSTJ(26)	2	PARJ(16)	0.0
PARJ(33)	0.8	PARJ(17)	0.0

PARP(82): UE IR cutoff at reference ecm, Pythia 0: 3.4 Pythia NOCR: 3.19
PARP(89): Reference ecm
PARp(90): UE IR cutoff ecm scaling power